

# Influence of Domain Wall on Magnetocaloric Effect in GdPt<sub>2</sub>

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The resistivity, magnetoresistance and in-field heat capacity measurements were performed on GdPt<sub>2</sub> intermetallic compound. The magnetocaloric parameters  $\Delta T_{ad}$  and  $-\Delta S$  were derived from the in-field heat capacity data. Comparison has been made between the magnetocaloric effect  $-\Delta S$  and difference in resistivity  $-\Delta\rho$  ( $=\rho(H) - \rho(0)$ ) as a function of temperature. There is distinct difference in the temperature dependence of  $-\Delta S$  and  $-\Delta\rho$  below the ferromagnetic transition temperature. However after removing the domain wall contribution from  $-\Delta\rho$ , the nature of  $-\Delta S$  and  $-\Delta\rho$  dependence as a function of temperature are similar. Our observation indicates that the domain wall contribution in magnetocaloric effect is negligible in spite of the fact that it has significant contribution in magnetotransport.

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## I. INTRODUCTION

The magnetocaloric effect (MCE) is defined as the adiabatic temperature change ( $\Delta T_{ad}$ ) or isothermal entropy change ( $-\Delta S$ ) of magnetic materials with the application of an external magnetic field. MCE has immense technological importance for magnetic cooling. In recent years the studies related with MCE has gained momentum due to the observation of giant MCE near room temperature<sup>1,2,3</sup>. The main focus in the study of MCE is concentrated to find out newer materials with large MCE. Apart from its technological importance, the MCE can give us valuable basic information about the magnetic materials like nature of magnetic ordering, metamagnetic transitions etc<sup>4</sup>.

The building block of ferromagnetic materials below ordering temperature are the magnetic domains which are separated by domain walls. MCE is related with the thermomagnetic properties of magnetic materials. Therefore magnetic domains as well as domain walls is expected to have effect on MCE. However the contribution of domain wall on MCE is not properly highlighted in the literature. Polycrystalline GdPt<sub>2</sub> compound crystallizes in a stable cubic MgCu<sub>2</sub> structure with ferromagnetic Curie temperature 31 K<sup>5</sup>. In this present work, the main objective is to find out how strong is the contribution of domain wall on MCE in GdPt<sub>2</sub>. Can it influence the temperature dependence of MCE so much that it leaves some strong signature in the dependence.

Gadolinium, having  $L = 0$ , has negligible crystalline electric field in GdPt<sub>2</sub> and should reach it's full moment value upon ordering and attain its full magnetic entropy value  $R\ln(2J + 1)$  or 17.3 J/mol K. Due to large moment of Gadolinium, GdPt<sub>2</sub> is expected to show reasonably large MCE. The magnetic and transport properties of GdPt<sub>2</sub> compound have been studied by various authors<sup>6,7</sup>. It is believed that the magnetic interaction of well-localized 4f magnetic moment of Gd are mediated by conduction electrons via RKKY interaction. Critical behavior of electrical resistivity was studied in the vicinity of the ordering temperature in the framework of the

molecular field theory<sup>7</sup>. To the best of our knowledge no report on the study of thermodynamic property of GdPt<sub>2</sub> compound is available in the literature. We have studied MCE as well as magnetotransport properties of GdPt<sub>2</sub>. Earlier reports<sup>8,9</sup> in the literature suggest that the dependence of magnetocaloric effect and magnetoresistance can be similar. The comparison of the thermodynamic and magnetotransport data is a novel method of gaining deeper understanding about magnetic materials. Keeping this context in mind, we have measured and compared the temperature dependence of different quantities  $-\Delta\rho$  and  $-\Delta S$ , one related with transport and the other related with thermodynamic properties.

## II. EXPERIMENTAL DETAILS

The binary polycrystalline sample was prepared by arc melting of constituent elements of purity better than 99.9% in Argon atmosphere. X-ray diffraction pattern confirms the single-phase nature of the compound which crystallizes in cubic MgCu<sub>2</sub> structure. Specific heat (C) measurements were performed using the semi-adiabatic heat-pulse method in the temperature interval 4-60 K in the presence of 10 and 70 kOe magnetic fields. The temperature interval of zero-field C measurement was 4-130 K. The temperature interval of C measurement in 5 kOe was 4-40 K. The temperature dependence of resistivity( $\rho$ ) in the absence of a field as well as in the presence of 5, 10 and 70 kOe magnetic fields were measured by the conventional four-probe method. The longitudinal magnetoresistance (MR) ( $\Delta\rho/\rho = \{\rho(H) - \rho(0)\}/\rho(0)$ ) measurements at 4, 10, 20, 40 and 80 K were carried out in the magnetic field up to 75 kOe.

## III. RESULTS AND DISCUSSION

The specific heat of GdPt<sub>2</sub> as a function of temperature at various constant magnetic field is plotted in Fig.1. In the presence of small external magnetic field ( $\simeq 10$  kOe) the peak position of C shifts to the higher temperature,

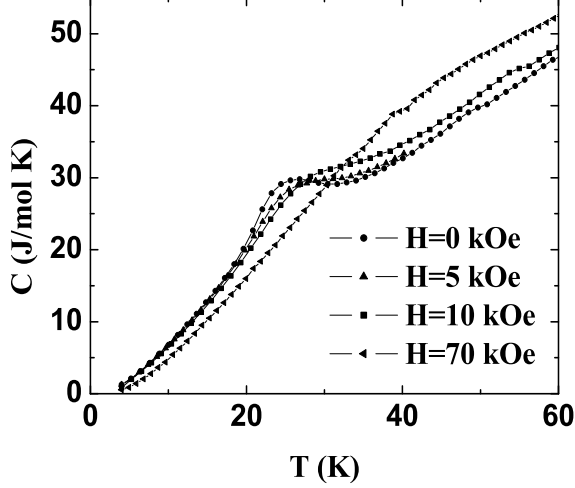


FIG. 1: Heat capacity ( $C$ ) as a function of temperature for  $\text{GdPt}_2$  at different constant magnetic fields

indicating the ferromagnetic nature of magnetic ordering. At higher magnetic field i.e. in 70 kOe field, the peak disappears completely.

To find out the magnetic contribution of specific heat we have fitted the zero-field  $C$  data using Debye integral along with linear contribution within the temperature interval 80 to 130 K and extrapolated the fitted data down to low temperature which is shown in Fig.2. The total specific heat  $C$  can be expressed as,

$$C = C_{el} + C_{ph} + C_{mag}$$

$C_{mag}$  is the magnetic part of specific heat.  $C_{el}$  and  $C_{ph}$  are respectively the electronic and phonon contribution of specific heat. The electronic part is of the form  $C_{el} = \gamma T$ , where  $\gamma$  is the electronic heat capacity coefficient. The phonon part, approximated as Debye model, is of the form  $C_{ph} = \mathcal{D}(\theta_D/T)$ , where  $\mathcal{D}(\theta_D/T)$  is the Debye function and  $\theta_D$  is the Debye temperature. The  $C$  data was fitted using

$$C_{el} + C_{ph} = \gamma T + \mathcal{D}(\theta_D/T)$$

in the temperature interval 80 to 130 K under the approximation that well above the transition temperature magnetic contribution is negligibly small. From fitting, the value of  $\gamma$  and  $\theta_D$  turns out to be 2.2 mJ/mol K<sup>2</sup> and 215 K respectively. Magnetic contribution of specific heat was obtained by subtracting the regenerated nonmagnetic contribution in the temperature range 4 to 130 K using the above mentioned  $\gamma$  and  $\theta_D$  value. The temperature dependence of  $C_{mag}$  is shown in the inset of Fig.2. From the inflection point of  $C_{mag}$  data, we obtained the ferromagnetic ordering temperature  $T_C = 29$  K which is close to the referred transition temperature

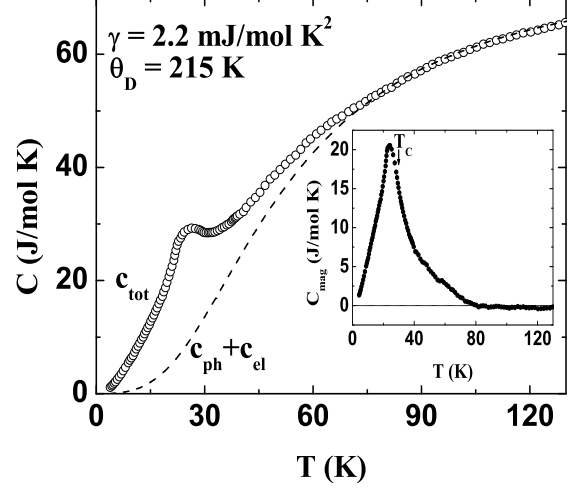


FIG. 2: Zero-field specific heat data as a function of temperature. Dashed line represents the lattice contribution of specific heat. Inset: magnetic contribution of specific heat as a function of temperature.

$T_C = 31$  K<sup>5</sup> from magnetization measurement. The maximum value of  $C_{mag}$  reaches 20.54 J/mol K. The magnetic contribution to the specific heat for equal-moment (EM) magnetic structure in Gd intermetallic compounds is expressed as<sup>10</sup>

$$C_{EM} = \frac{5J(J+1)}{(2J^2 + 2J + 1)} R$$

Gadolinium having  $J=7/2$ , yield  $C_{EM} = 20.15$  J/mol K. Our experimentally observed value of  $C_{mag}$  which is very close to the  $C_{EM}$  value indicates that the magnetic configuration in  $\text{GdPt}_2$  is equal-moment in nature. Moreover a noticeable magnetic contribution persists well above the transition temperature. The magnetic entropy of Gd intermetallic compounds attain its full value  $R \ln(2J+1)$  or 17.3 J/mol K just above the ordering temperature<sup>11</sup>. The calculated magnetic entropy of our sample is 17.6 J/mol K at the ordering temperature which is in good agreement with  $R \ln 8$  or 17.3 J/mol K. This indicate that the Gd ions ordered with full moments within  $\text{GdPt}_2$ .

The isothermal entropy change ( $-\Delta S$ ) and adiabatic temperature change ( $\Delta T_{ad}$ ) was obtained from total entropy, which was calculated from experimental  $C$  data as a function of temperature at various constant magnetic fields. To calculate the entropy contribution for 0 to 4 K, the linear variation of  $C$  data was considered. The difference between the two entropy curves from zero-field to in field for isothermal translation results in  $-\Delta S$  and isentropic subtraction gives  $\Delta T_{ad}$ . The temperature dependence of  $-\Delta S$  and  $\Delta T_{ad}$  for 5, 10 and 70 kOe magnetic fields are plotted in Fig.3 and Fig.4 respectively. The plot of  $\Delta T_{ad}$  as a function of temperature shows a positive caret-like shape with maxima around the mag-

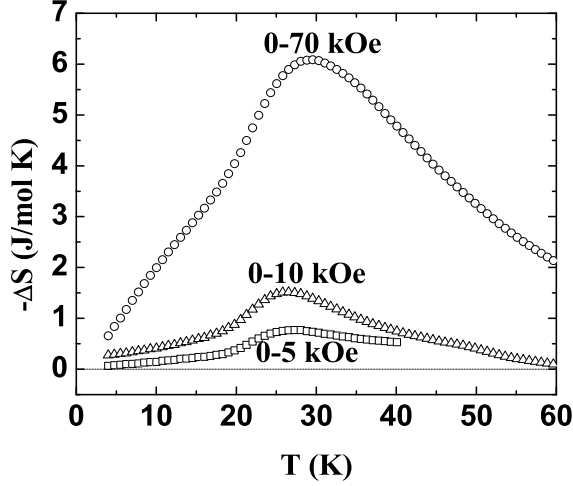


FIG. 3: Isothermal entropy change  $-\Delta S$  as a function of temperature calculated from the heat capacity data at constant magnetic fields.

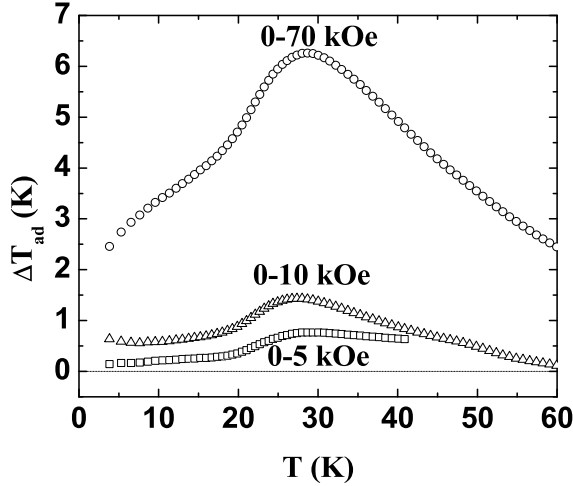


FIG. 4: Adiabatic temperature change  $\Delta T_{ad}$  as a function of temperature calculated from the heat capacity data at constant magnetic fields.

netic ordering temperature and  $\Delta T_{ad}$  positive in the entire temperature range for all magnetic fields, which is expected for ferromagnetic materials. The temperature dependence of both  $\Delta T_{ad}$  and  $-\Delta S$  are almost similar to each other. The value of  $\Delta T_{ad}$  around the magnetic ordering temperature for 5, 10 and 70 kOe magnetic fields are respectively 0.8, 1.4 and 6.3 K i.e. the rate of change of  $\Delta T_{ad}$  as a function of magnetic field decreases with increasing fields. This feature also indicate the ferromagnetic nature of GdPt<sub>2</sub> compounds.

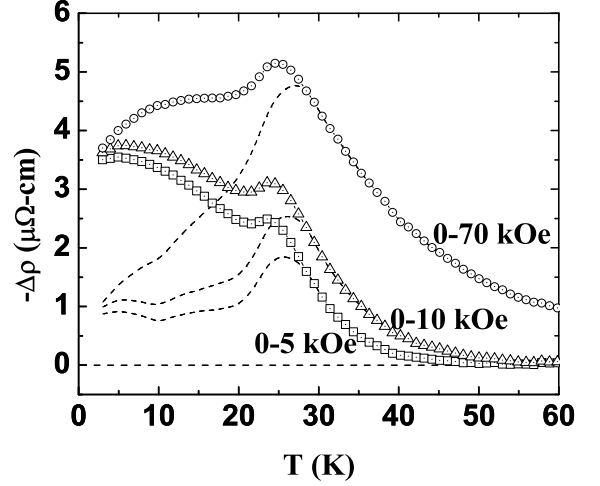


FIG. 5: Differences in resistivity  $-\Delta\rho$  are plotted as a function of temperature with different symbols. Dashed line curves are the  $-\Delta\rho$  vs. temperature curve after subtracting domain wall contribution in magnetoresistance.

The temperature dependence of  $-\Delta\rho$  is shown in Fig.5 which was calculated from experimental resistivity data from 4 to 60 K at various constant magnetic fields. Below the magnetic ordering temperature the variation of  $-\Delta\rho$  and  $\Delta T_{ad}$  or  $-\Delta S$  with temperature are distinctly different for all the three magnetic fields 5, 10 and 70 kOe. It has been shown earlier that the temperature dependence of  $-\Delta\rho$  and  $-\Delta S$  can be similar<sup>8,9</sup>. It implies that for a ferromagnetic compound with the increasing (decreasing) magnitude of  $-\Delta S$  the magnitude of  $-\Delta\rho$  is expected to increase (decrease) as a function of temperature. As a result one can expect that  $-\Delta\rho$  decreases gradually as does  $-\Delta S$  with decreasing temperature after showing a maxima around ferromagnetic transition temperature of GdPt<sub>2</sub>. In contrast to the expectation,  $-\Delta\rho$  shows a broad hump at low temperature. To find out the main cause behind the dissimilar behavior between  $-\Delta\rho$  and MCE we have performed MR measurement as function of field at different constant temperatures, which is shown in Fig.6(A). The MR curves at constant temperature clearly demonstrate the existence of significant low field magnetoresistance (LFMR) originating from magnetic domain wall at low temperature. In the paramagnetic state the low field MR vanishes and at higher temperature i.e. at 80 K MR follows  $-H^2$  magnetic field dependence as indicated by dashed line in Fig.6(A), which is an indication of enhanced spin fluctuation even at this high temperature. The LFMR value was obtained by extrapolating 5 kOe data to zero field which is shown in Fig.6(B). The LFMR below ferromagnetic ordering temperature of polycrystalline compounds originates due to the suppression of domain wall scattering of conduction electrons with the application of magnetic field. Domain

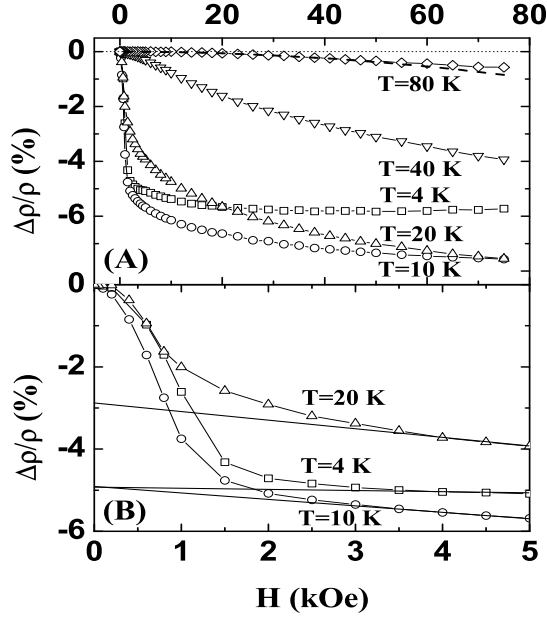


FIG. 6: (A) Magnetoresistance as a function of field at various constant temperatures. (B) LFMR at different temperatures calculated by extrapolating 5 kOe data to zero field.

wall contribution of MR in GdPt<sub>2</sub> remains unchanged below 10 K and absent above the ferromagnetic transition temperature. In the intermediate temperatures it varies almost linearly as a function of temperature. After removing the domain wall contribution from the total resistivity difference the broad hump in  $-\Delta\rho$  vanishes which is shown in Fig.5 by dashed line and the nature of  $-\Delta\rho$  and  $-\Delta S$  curves as a function of temperature comes out to be similar. These observations indicate that the dissimilar temperature dependence of  $-\Delta\rho$  and  $-\Delta S$  in GdPt<sub>2</sub> is originating from the fact that the magnetic domain wall has significant contribution in  $\Delta\rho$  but negligible influence on MCE.

#### IV. SUMMARY

MCE along with transport property have been studied in GdPt<sub>2</sub> compound. We have observed distinct difference in temperature dependence of  $-\Delta\rho$  and  $-\Delta S$  below the ferromagnetic ordering temperature. However if we remove the domain wall contribution from  $-\Delta\rho$ , then the nature of  $-\Delta\rho$  and  $-\Delta S$  curves as a function of temperature are similar. It highlights the fact that the domain wall contribution in magnetocaloric effect is negligible in spite of the fact that it has significant contribution in transport in GdPt<sub>2</sub>.

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